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SUITCEYES

1 Jan 2018 - 31 Dec 2020

Smart, User-friendly, Interactive, Tactual, Cognition-Enhancer, that Yields Extended Sensosphere
Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces

[D1.5]

Public Report

Courtesy of LightHouse for the Blind and Visually Impaired, see http://lighthouse-sf.org

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Dissemination level		
PU	PUBLIC, fully open, e.g. web	PU
CO	CONFIDENTIAL, restricted under conditions set out in Model Grant Agreement	
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Deliverable Type		
R	Document, report (excluding the periodic and final reports)	R
DEM	Demonstrator, pilot, prototype, plan designs	
DEC	Websites, patents filing, press & media actions, videos, etc.	
OTHER	Software, technical diagram, etc.	

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Executive Summary

This document, “D1.5 – Public Report” is the final deliverable in the project and is written as part of *WP1, Project Management and Coordination*.

This report summarises the overall project results and achievements for a general public consumption. The idea behind this document has been to provide a simple, non-technical popular scientific overview of the project for a broad audience. Since the readers may not be familiar with the project, this document provides a brief overview of the project from its beginning to its conclusions and outlines some of the core developments and results of the project. That is, the report includes small subsections on the main outcomes of the project and some of the noteworthy achievements have been highlighted.

The report starts with some background information about deafblindness and how the idea for the project was initiated, then a number of subsections relate to different work packages (without referring to the term work package) and their core results are presented. The effects of the Covid pandemic on the project are outlined and some of the highlights from the project (e.g., the symposia organized by the project) are briefly presented. As a concluding remark, those who have enriched the conduct of the project have been acknowledged and thanked.

The report concludes with a list of references which remains very short due to the nature of this report. However, links are provided to other online resources and also the project website, where the interested reader can access the full set of publications resulting from the project.

Note for the reviewers: We intend to publish this report, after receiving your review feedback, both in print as presented here and a more accessible digital format (e.g., with further description of the images included) to be disseminated to the interested parties and those who have somehow supported the project during its lifetime. The main body of the deliverable is designed to suit a popular scientific report, hence the difference in page sizes and format.

SUITCEYES

Smart, **U**ser-friendly, **I**nteractive, **T**actual, **C**ognition-**E**nhancer, **Y**ielding **E**xtended **S**ensosphere
- Appropriating sensor technologies, machine learning, gamification and smart haptic interfaces

Improving the quality of life for people with deafblindness through intelligent haptic technologies

SUITCEYES (1 January 2018 – 30 June 2021) is an EU-funded, HORIZON 2020 project with the aim to develop haptic communication technologies for people with deafblindness. This short report provides a non-technical over-view of the project from the idea conception to the final results.

This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under grant agreement No 780814.

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Useful ICT innovations are continuously developed, improving the quality of life for many people. However, such solutions do not typically address the needs and preferences of people with deafblindness. A core aim in the SUITCEYES project has been to develop communication technologies that are designed with this target group specifically in focus.

deafblindness

The term deafblindness, also referred to as *dual sensory impairment* or *combined vision and hearing loss* (see e.g., Wittich, Southall et al. 2013) does not necessarily mean a total loss of vision or hearing. The definitions of deafblindness can vary (e.g., see Larsen and Damen 2014)[1] but the Nordic definition adopted within the project defines deafblindness as "a **combined vision and hearing impairment** of such severity that it is hard for the impaired senses to compensate for each other. Thus, deafblindness is a **distinct disability**." As highlighted in some of the related definitions and discussions, *communication*, *access to information*, *orientation & mobility*, *social interaction*, and

Image is used with permission by Mo Gård

independence remain among the challenges faced by those who live with deafblindness.

Often deafblindness types have been categorised as congenital or acquired where the latter refers to acquiring deafblindness at different stages of life through illness, accident, or old age. However, depending on the time of

[1] Also see: Deafblind UK: https://deafblind.org.uk/information-advice/what-is-deafblindness/#:~:text=Deafblindness%20is%20the%20loss%20of,over%20a%20period%20of%20time, Sense: https://www.sense.org.uk/get-support/information-and-advice/conditions/what-is-deafblindness/; OR Individuals with Disabilities Act (IDEA): https://sites.ed.gov/idea/regs/b/a/300.8/c/2, 29 U.S. Code § 1905: https://www.law.cornell.edu/uscode/text/29/1905, https://definitions.uslegal.com/d/deaf-blindness/, the National Centre on Deaf-Blindness: https://www.nationaldb.org/info-center/deaf-blindness-overview/; OR Spanish Federation of Associations of Deafblind People: https://www.fasocide.org/en/deafblind-community/deafblindness-definition/. OR Deafblind Information Australia: https://www.deafblindinformation.org.au/about-deafblindness/

sensory loss (pre-lingual or post-lingual), order of sensory loss (blindness first or deafness first), the levels of impairments in either of the senses (residual sight or hearing or both vs profound deafness and or blindness), the age and life situation at the time of acquiring deafblindness, presence of other functional and/or cognitive disabilities, national norms and levels of support in providing appropriate educational programmes, and more, there is a great diversity among those with deafblindness. As a result, traditional simple categorisations do not provide sufficient frameworks for understanding the diversity of life situations and experiences of the individuals. Therefore, improved user-centred approaches are needed in discussing the issues of relevance.

numbers – There are no accurate statistics on the number of people who live with deafblindness and estimations vary greatly. According to a report by the World Federation of the Deafblind[2] between 0.2% to 2% of the world population live with deafblindness, deafblindness becomes more common as people age and deafblindness is higher in women than men in most countries. With the aging population these numbers are estimated to rise further in the coming years. According to Sense[3], there are "approximately over 390,000 people in the UK who are deafblind, with this figure likely to increase to over 600,000 by 2035"[4]. In another report by the European Deafblind Network the number of people with deafblindness, only within Europe, is estimated to be well over 2.5 million[5].

equal opportunities for all? – Meanwhile basic human rights regarding accessibility, inclusion, and participation have been declared in national and international directives. The United Nations' Universal Declaration of Human Rights[6] proclaims human rights for all people, including people with disabilities (article 25), "to seek, receive and impart information and ideas through any media" (article 19); "the right to education" (article 26), "the right to freely participate in the cultural life and to enjoy the arts" (article-27). The Charter of Fundamental Rights of the European Union[7], mirrors these basic rights closely. Similarly, the Convention on the rights of persons with disabilities[8] is put forward in

[2] https://senseinternational.org.uk/sites/default/files/WFDB_complete_Final.pdf
[3] https://www.sense.org.uk/about/
[4] https://www.sense.org.uk/get-support/information-and-advice/conditions/what-is-deafblindness/
[5] http://siketvak.hu/wp-content/uploads/2014/07/Final-Report-Deafblind-Indicators.pdf
[6] https://www.un.org/en/universal-declaration-human-rights/
[7] https://www.citizensinformation.ie/en/government_in_ireland/european_government/eu_law/charter_of_fundamental_rights.html#:~:text=The%20Charter%20of%20Fundamental%20Rights,with%20the%20Treaty%20of%20Lisbon.
[8] https://www.un.org/disabilities/documents/convention/convoptprot-e.pdf

order to ensure "*the full and equal enjoyment of all human rights and fundamental freedoms by all persons with disabilities*". Article 9: Accessibility includes an equal right "*to **information** and **communications**, including information and communications technologies and systems*".

Despite these and similar measures, in practice, the needs and life circumstances of these members of society are often overlooked and accessibility to information, and inclusion of persons with disabilities in communication and cultural experiences remain limited. With this background in mind, SUITCEYES has taken a step towards addressing some of the shortcomings by developing innovative technologies for information capture and exchange for and by people with deafblindness. The benefits and application areas are not limited to this group and the developed solutions are scalable to other areas.

different views on disability – Traditionally, medical experts have defined disability in terms of facts about general physical or intellectual characteristics of a human body. In this medical view of disability, people are seen to be disabled by their impairments or differences[9]. This medical model of disability has, however, been broadly contested. Brisenden (1986), for example, has questioned "whether these facts can be adequately interpreted" and has argued that reliance solely on such facts and undue emphasis on clinical diagnosis may indeed lead to "distortion and misunderstanding and to a view of disabled people as a category of rejects, as people flawed in some aspect of their humanity". He further argues that "in order to understand disability as an experience, as a lived thing, we need much more than the medical 'facts', however necessary these are in determining medication". Critics of the medical model propose that by viewing disability as 'something wrong with the person', the needs of people are overlooked and hence leading to a lack of independence, choice and control over one's own life.

The social model views impairment and disability as separate entities. Disability is a social construct seen to be caused by the way society is organised and involving discriminatory policies and practices. Mike Oliver, who writes in a discussion paper thirty years after to the social model was formulated: "The idea behind the social model of disability

9 http://www.disabilitynottinghamshire.org.uk/index.php/about/social-model-vs-medical-model-of-disability/

stemmed from the Fundamental Principles of Disability document first published in the mid-1970s (UPIAS 1976), which argued that we were not disabled by our impairments but by the disabling barriers we faced in society" (Oliver 2013). This is the view of disability that has been adopted in the SUITCEYES project. We have argued that often sight and hearing are taken for granted in developing our policies, technologies, designs and activities. For example, informational cues (e.g., room numbers in written format outside each office, or the sound that a microwave oven makes when the cooking cycle is concluded) for sighted and hearing people are readily made available and fully accepted and expected, however, making the same information available to people with sensory loss in other formats (e.g., in Braille or by haptic signals, i.e., messages delivered through the sense of touch) is seen as an added extra and not the norm. In this way, the needs of some members of society are privileged while the needs of others are overlooked. A main ambition of SUITCEYES has been to create a more equal playing field.

It should be noted that even the social model has been criticised and discussed widely. There are also other alternative and / or additional views, such as the capability approach (Sen 1999) (see also: Mitra 2006), the functional limitation paradigm (Nagi 1965), a human rights model of disability (Degener 2017)[10] and others.

In this short report, we provide a non-technical overview of the project and its achievements.

the beginnings – The idea of the SUITCEYES project came about through discussions with a counsellor at the National Agency for Special Needs Education and Schools in Swedish[11], Thomas Ragnarsson, who was also a member of the Swedish National Resource Centre for Deafblindness[12]. Thomas specialised in assistive technologies for children with visual impairments and deafblindness. The technologies available at the time, to support school children with deafblindness (both acquired and congenital) seemed very limited and a wish for more useful technologies was stressed. Based on those initial expressed needs further communications were had with many others who worked with either issues of deafblindness (e.g., Henrik Hildemar, ICT instructor at Mo Gård[13]; Berit Rönnåsen, counsellor at SPSM) or other issues related to the project (e.g., Lars Sandman, professor of

[10] Also see: Degener, 2014 at: file:///E:/Nasrine%20Olson%20(HDD)/H%C3%A4mtade%20Filer/Degener-humanrightsmodeofdisability.pdf

[11] https://spsm.se/

[12] https://nkcdb.se/

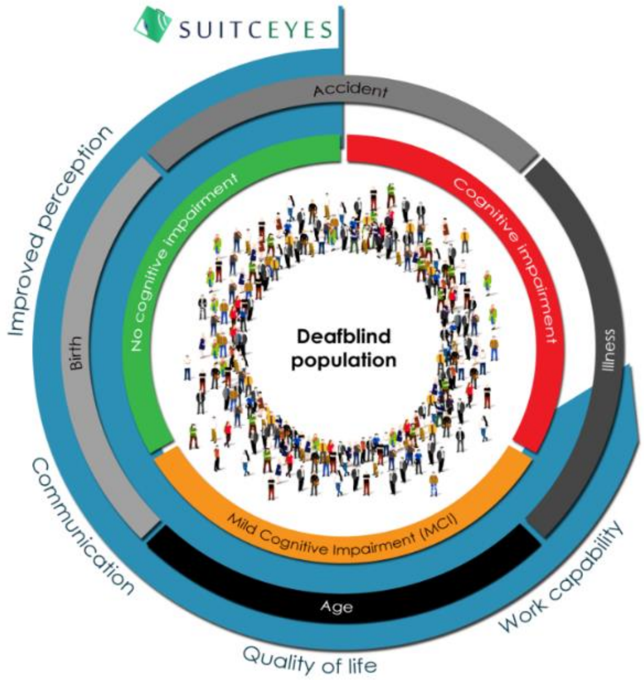
[13] https://www.mogard.se/

health-care ethics and Director of the National Centre for Priorities in Health; Lissa Holloway-Attaway associate professor in Media Aesthetics and Narration) and many others who all contributed to forming the idea of the project.

A proposal was formed involving a consortium of seven partner organizations from seven European countries. These included five academic and two non-academic organisations as follows:

Participating organisation		Country	
1- Högskolan i Borås (HB) – Project coordination		SE	
2- ITI, Centre for Research & Technology Hellas (CERTH)		GR	
3- Hochschule Offenburg (HSO)		DE	
4- University of Leeds (UNIVLEEDS)		UK	
5- Eindhoven University of Technology (TU/e)		NL	
6- Les Doigts Qui Rêvent (LDQR)		FR	
7- Harpo Sp. z o.o. (HARPO)		PL	

The proposal was successful with a high score of 14.5 and subsequently the project started on the 1st of January 2018. The duration of the project was planned to be three years, however, due to the delays caused by the COVID-19 pandemic the duration of the project was extended to the end of June 2021, although without extra funding.



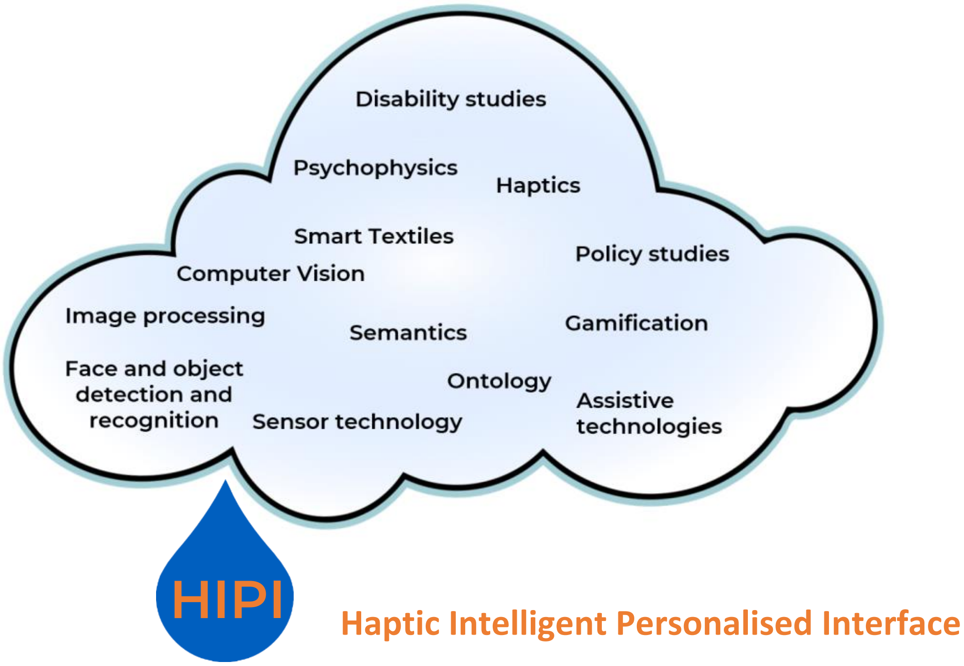
the idea

The overall objective of SUITCEYES has been to improve the level of independence and participation of individuals with deafblindness and to enhance their communication, perception of the environment, knowledge acquisition, and conduct of daily routines.

The core idea of SUITCEYES involves a novel, flexible and expandable mode of haptic communication via soft interfaces, where three challenges have been addressed:

(i) perception of the environment
(ii) communication and exchange of semantic content
(iii) learning and joyful life experiences

components – Towards this, SUITCEYES brought together expertise from user and policy studies, disability studies, psychophysics and haptics, machine learning and computer vision, sensor technologies, semantics, gamification and smart textiles to develop what we call a **Haptic Intelligent Personalised Interface**.



communication and deafblindness – Due to the vast diversity in the causes, order and time of deafblindness, and based on personal preferences, modes of communication vary greatly among those with deafblindness. Some have used spoken and written languages throughout their lives and continue to do so. These individuals, depending on the level of sensory loss may use various assistive tools and devices such as text magnification, hearing aids, cochlear implants and more. Others use braille, Tadoma, tactile lipreading, finger spelling, tactile sign language, Social Haptic Communication and more. Some utilize multiple modes of communication. Haptic communication, or communication by touch, often involves interpersonal contact. This is not always possible and at times (e.g., during pandemics) not safe. While Braille readers provide a way to haptically communicate text or speech, they do not provide social context. Social haptic communication is therefore often used to provide contextual information in addition to information received by other means. For example, at a conference a tactile sign language interpreter can interpret the contents of the different talks, while a Social Haptic Communication interpreter can inform the receiver about other contextual information, such as people laughing, or clapping, or the room being crowded, and so on. Social Haptic Communication consists of meaningful hand gestures made on appropriate body parts such as the back or arms of the receiver.

a b c

Figure 1. - A few Social-Haptic signals [referring to car (a), blue (b), and good night (c)][14]

In SUITCEYES, we opted to emulate Social Haptic Communication by forming haptic patterns using vibrotactile actuators. This will be further explained later in this report.

project research activities – Initially to inform the project of further needs and the priorities of people with deafblindness, an extensive user study was conducted involving 81 interviews with 79 participants by the academic partners situated in the UK, Sweden, Germany, Netherlands, and Greece. Meanwhile sensor technologies and computer vision algorithms were developed to capture environmental cues and to detect and recognise objects, scenes, and faces. To convey the captured information, a simple vocabulary of haptograms was developed that was inspired by Social Haptic Communication. A number of games were also developed with three main objectives, namely to facilitate learning the activation patterns and the use of our technologies, to assist in educational programs for children, and to create enjoyable recreation. These technologies are brought together in a smart-textile-based Haptic Intelligent Personalised Interface or what we call the HIPI.

The following sections elaborate on each of these steps.

[14] Images used with permission. Source: http://haptisk.nkcdb.se/

user studies

The project started by investigating what was most important for people with deafblindness. We interviewed 79 people in five European countries. Through these interviews many insightful personal experiences were shared with us. Many of the participants had lost their sight or hearing due to conditions such as Usher syndrome, others due to accidents and age-related issues. In many cases, it was a progressive impairment resulting in worsening hearing and vision.

Some of the participants led very active lives, with employment, extensive travelling, sports activities (e.g., swimming, skiing), and hobbies (reading through using Braille, cooking, gardening, crafts, party games, solving crosswords and sudoku, model building, music composition, even photography). The educational backgrounds of the participants were varied (many with higher education, e.g., in psychology, pedagogy, etc.) as were their employment experiences (e.g., from unemployed to jobs as graphic designer, a computer scientist, educator, and more). The level of support that they received was also varied and somewhat related to the countries in which these participants lived.

Deafblindness was perceived as a significant barrier to communication and information reception. Many small daily activities, that others take for granted, involved major organisation for the participants. Just a simple outing to, say, the swimming pool would involve getting ready, matching the colours of clothing, walking out in the streets that may be under construction, catching the right bus, handing over the right amount of money, finding an empty seat, and much more even before arriving at the swimming pool. Or after having done the weekly shopping a lot more planning and careful placing of the bought items would be needed so that not to confuse different items of the same shape (e.g., a can of green peas with a can of sweet corn, or a bottle of bleach with a bottle of washing up liquid) at the time of use. Even other simple

> I was born deaf... I was 56 when I became blind.
>
> Every day I dream that I can see again. That's when I sleep. I think that I am driving a car as usual, I dream very much about that and then I wake up, I am blind again…
>
> When I became blind, so all my life… well, it disappeared. It felt like I died...
>
> I am very curious too... life is exciting. I always want to learn new things; I want to live long. I want to be 140 years.
>
> (Quotes from an interview with an 81-year-old male participant)

activities would become more complex. One participant explained: *'... it would be nice to have some indication of when I hold the paper correctly to read it. I just take a picture of a piece and I am not certain that I get all the text, I may take the picture too much to the right and then I miss some text.'* (Female, 50- 54). Each label, each street name, many designs, and arrangements bear information for those who can see and hear but not for those with sensory impairments. Even in most essential functions, information is lacking. One participant mentioned: '*The accessible toilet can be a real pain at times because they don't have things in the right places. They keep changing the blowers or where the hand towels are and so on...*' (Male, 60-64). The simplest things are not adapted to suit everyone: *'I am thinking about washing machines. They have more touch buttons now. You cannot feel where the buttons are and even if you find the buttons, you cannot see what is on the display.'* (Female, 40-44).

We asked the participants about the things they most wanted to do but could not at the moment, and how technology could help. Top of the list were getting information about the wider environment and being able to move about freely, especially outside. As mentioned, the situations and experiences of people with deafblindness are very varied and participants highlighted the importance of developing devices that they can adapt to work well for themselves. They also had some concerns, especially about the cost, reliability and quality of devices. They further wanted to make sure that in using the HIPI, they would not lose support that they had already, such as interpreter guides, who are vital for social connection.

These examples illustrate the importance of ensuring that the technologies developed in the project are flexible and adaptable to different needs and situations. We opted to focus attention on awareness of one's surroundings and communication, as these were the two most important needs identified by participants, and to ensure that the work conducted could be adapted to other situations in future.

policy studies

Researching policy was also an important part of the project: understanding how the political and legal situations varied in different countries, and how these might affect the technology. This is particularly important, as this can affect both the funding available and decisions about who is eligible for a given device; and because regulations on privacy and data management can have a significant impact on the use of technologies such as computer vision, which form part of the project.

Five researchers wrote reports on law and policy in the five countries (UK, SE, DE, NL, GR) and the European Union. We carried out research on: 1) the situation of people with deafblindness, 2) law and policy on equality, whether and how people could get access to personal devices and accessibility of the environment, and 3) regulations on new technologies, artificial intelligence and machine learning for example, and how they might affect the work of SUITCEYES. A summary of our findings follows.

People with deafblindness are not recognised properly by governments and organisations. They are often left out and their support needs are often not taken into account. For example, sign language is not legally recognised in many countries.

We found that policies were very different in different countries, with varying definitions of "deafblindness" and that in general policies relating to technology are currently moving extremely quickly in response to rapid developments in the fields of robotics and artificial intelligence.

International treaties, especially the Convention on the Rights of People with Disabilities[15], set out important rights for disabled people and all of the countries in SUITCEYES have signed up to this. In recent years the EU has issued some directives on accessibility, which countries have to follow. Therefore, the countries have similar laws and policy on accessibility. However, the laws are put into practice differently in the various countries. For example, face and object recognition are not explicitly addressed in the current legal framework in Greece, while in Germany face recognition and other biometric data may only be processed with the consent of the person concerned. There are still many gaps from the point of view of disabled people and people with deafblindness. In practice, getting hold of equipment through health and social service organisations is often difficult, complicated and stressful. There is still a long way to go to make society accessible to people with deafblindness.

New technology such as artificial intelligence can be used to bring many benefits but it can also do harm. The EU and some countries have introduced new regulations based on risk, with the aim of making sure AI is trustworthy. Disabled people have so far mostly supported

15 https://www.un.org/disabilities/documents/convention/convoptprot-e.pdf

the use of new technologies but they are concerned about how their data is used and about privacy. This is important for SUITCEYES and other similar projects.

In the user studies, the participants emphasised they should not have to compromise on privacy in order to use technology. Ownership of data is important. However, disabled people have not been involved in the discussions about regulation of new technologies, especially at national level. For both EU projects and governments, an important step for this would be to set up a way of communicating regularly with disabled people. Educating disabled people in technology and designers and regulators in disability issues is also necessary.

sensor technologies

Work on the technological side has tried to reflect the important needs identified in user studies. Considering the great diversity of those with deafblindness we have opted for a modular approach so that different users can use different components and therefore have a system that is tailored to their needs. We have developed a system that can recognise Bluetooth beacons, called iBeacons in the environment, so that people, objects and landmarks in the environment can be marked, and their proximity detected. We have also used cameras to capture images so that faces, objects and locations can be recognised by the computer vision described in the next section. With this, it is possible to direct users through haptic signals to objects that are of particular interest to them, without the need to try to convey every single item to them.

visual analysis

The main task of the Visual Analysis (VA) and Semantic Reasoning (SR) modules of the SUITCEYES is to capture and interpret the surrounding environment of people with Deafblindness. Visual input from the camera mounted on the smart garment, called the HIPI (Haptic Intelligent Personal Interface), is fed to the VA component, which extracts and recognizes, with the use of Artificial Intelligence algorithms, the detected concepts, i.e., surrounding objects, faces, or scenes (see Figure 2).

For example, a person may be located in an office with three other people in the room, and a laptop and coffee cup on the table. This information is captured by the camera and the scene (an office), the three people and the items on the table are detected and recognized. The VA component can also distinguish between the known and unknown people and in fact whether a person is wearing a mask or not.

Figure 2. Objects and faces detected and recognized by the VA component of HIPI.

This information is then fed to the SR component, which is coupled with a semantic knowledge graph (also called an "ontology"), semantically aggregating the multimodal information from the analyses and inferring higher-level derivations. Specific predefined queries can be put to the SR component. An example of a predefined query and the respective answer is shown below.

Query: Where is my <phone> now?

Your <phone> is located on your <left>, <close to> you.

The outputs from the SR component are fed back to the HIPI garments, with the help of haptograms.

haptograms and haptic feedback

A haptogram, as developed within SUITCEYES, is a tactile symbol or a synthetically generated haptic pattern with a meaning to be communicated as stimuli to the human body. Haptograms are typically formed by activation of a sequence of actuator motors. The shape and meaning of the current set of haptograms are inspired by Social Haptic Communication (SHC) hand gestures on different parts of the body. This is in order to improve recognition and learnability. The design of haptograms is not only constrained by the grid-size available but also how perceptible they are as defined by psychophysical experiments. The images below provide an example of how the concept “danger” is conveyed in SHC vs. by means of a haptogram.

Figure 3a: The hand gesture for the word “danger in SHC

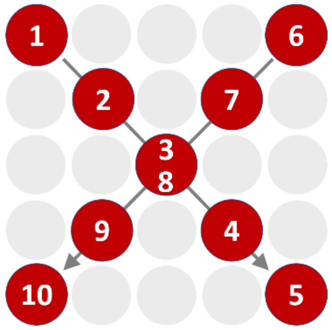


Figure 3b: The haptogram for the word “danger”

By placing vibrotactile actuators within a piece of clothing, one can mimic the act of drawing a shape on the body of a receiver. In this way we map the respective information to the haptic space and the user is informed with respect to specific predefined queries that have been addressed to the SR component. For example, an individual with deafblindness can enter a space and then ask questions such as “where am I” or “where is my phone”.

Social Haptic Communication messages are delivered from one person to another using the sense of touch - delivering haptograms through a garment is much more challenging! We have ultimately settled on vibration motors – like those used in a mobile phone – to convey information, because they are small and require little energy. We explored a range of other approaches – linear actuators and solenoids to provide tapping or pressing sensations; or thermal elements that could apply hot or cold sensations – but these all represented the challenge of being significantly bulkier than vibration motors, and therefore not appropriate for a wearable device.

smart textiles

During SUITCEYES we have developed a full-fledged textile-based interface for tactile communication. The classical definition of a smart textile item is “a textile able to take stimulus from the outside of the textile as input and give response from itself, as output”. This is indeed what is achieved here. Sensors, capturing the stimulus, have been incorporated as well as actuators, giving the response. The approach has been to advance the front of scientific outcomes denoted as haptic textiles by fabric construction, integration strategies, wire management, expression, textile realism, usability, finishing and production. In terms of clothing technology, a wealth of solutions has been developed (Figure 4); piping, constrictor for the size-span-tightness-maintenance problem, pocket matrix for vibro-tactile elements, 3D printed trims for fixation of directional dependent sensors, housings for vibro-tactile elements, wire management, lining, multipanel systems etc. The project has made connections between psychophysics and clothing technology which surprisingly has not been especially strong in either field so far. Still, the tactual and garments are inherently linked. Already without any arrangements of actuators on and in the textiles, garments - as in fashion - are related to communication. But this is vision-based. Within the project we have been approaching the sparsely investigated area of haptic communication of clothing itself.

We have developed the integration strategy of how and at what stage in the production process to realize physical mechanisms. We have developed an “A-B-C” planning for making textile wearables. We have worked much with creating body maps for different aspects such as weight tolerating zones, zones where bending is performed, zones where there is little change of curvature between convexity and concavity, etc. all these aiming for guiding beyond the intuitive tacit knowledge often employed- Here 3D scanning studies have been performed. The discrepancy between dynamics on the human skin and dynamics due to textile and textile constructions have been highlighted.

New concepts have been studied and prototypes made. This includes “null user interfaces” i.e., user interfaces based on the fact that textiles take part in most of every-day activities and as such could be used for putting on and putting off operations of functions. This kind of interfaces have a more or less extinct learning curve and is valuable for unburden from cognitive load. Tech-packs – detailed descriptions of how to produce a garment, common in the textile industry, have been expanded to also include electronics and mounting thereof. Another concept is the making of one-to-many tactual communication devices, (see below). Here the two-dimensionality needed for a rich communication speaks for textiles as the enabler for this.

Figure 4 -- Some clothing technology solutions developed in the SUITCEYES project (inside of HIPI vests) – (a) Horizontal constrictor straps for size-span-tightness-maintenance problem; (b) vertical constrictor straps for size-span-tightness-maintenance problem; (c) 3D printed housings for fixation of directional dependent sensors + coating it with textiles; (d) 3D printed fixation plates trims for anchoring sensors (in this case screwed together); (e) pocket matrix for vibro-tactile elements; (f) 3D printed housings for vibro-tactile elements; (g) Tunnel systems between back and front for wire management (allowing for movement); (h) Mesh systems for ventilating devices; (j) Balanced weights (here the power bank); (k) Zippers for smooth lining (not shown) hiding the electronics

understanding haptic perception to improve usability

The information that we extract via our senses does not always match the world around us. Common examples of this are perceptual illusions. While visual illusions are most well-known, illusions can occur in each of our senses. This includes our sense of touch, also known as haptic perception. In the SUITCEYES project we developed a platform, named HIPI, that provides information about a user's surroundings via haptic feedback. Therefore, it is important to understand how haptic information is perceived as this allows us to anticipate and compensate for possible distortions in the perceptual representation. By doing so, the ease of use of the provided haptic information increases considerably.

Our sense of touch can be used to perceive several types of information such as temperature, pressure and vibration. We briefly explored the use of temperature for providing haptic feedback. While this can be useful in the context of providing information about emotions, thermal transfer takes time and therefore it is a rather slow way of providing information. Additionally, the devices required to provide sufficient pressure for signals to be perceivable were too bulky to be integrated into a garment. Therefore, we decided to focus on using vibration for haptic feedback. Vibrations can be provided using small inexpensive vibration motors.

First, we explored perception of vibration pulse sequences. A vibration pulse is created by switching a vibration motor on and off. By doing this repetitively a sequence of vibration pulses can be created. Such vibration pulse sequences can be used to provide information about numbers and quantities, but also to provide tactile Morse code. In our first study we found that the number of vibration pulses is perceived with fewer mistakes if vibration pulses were grouped in time. This means that, for instance, six was presented in two groups of three pulses. In a second study we explored whether tactile Morse code can be learned in a fully tactile way without ever having seen or heard a visual or auditory representation of the Morse code alphabet. All participants in our study were able to learn at least 15 letters in 30 minutes of practice and some participants were able to learn the full alphabet in this short time. Directly after, they were able to recognize words that consisted of the letters they had learned. However, mistakes increased rapidly with word length. Also, it takes quite a long time to display tactile Morse code. Therefore, we conclude that tactile Morse code is indeed useful but mainly for short messages.

Next, we focused on vibration patterns that can be displayed using multiple vibration motors distributed across the back. Vibration can be used to trace a shape across the back by sequentially switching motors at different locations on and off. However, perception varies across the back and this can lead to feeling a shape different from what was intended. Therefore, it was important to understand how the distance between two vibrations at different locations is perceived.

We found that the perceived distance can vary considerably depending on how and where the vibrations are presented. Distances felt smallest when two vibrations were presented simultaneously instead of sequentially. Furthermore, horizontal distances were perceived differently from vertical distances and distances that cross the spine were perceived as largest. We also investigated how the orientation between two vibrations is perceived. We found that most orientations were perceived to be more horizontal than they were. This means that shapes drawn on the back with vibration can be perceived to be compressed in the vertical direction. To compensate for this, we positioned the motors vertically further apart than horizontally in the SUITCEYES HIPI.

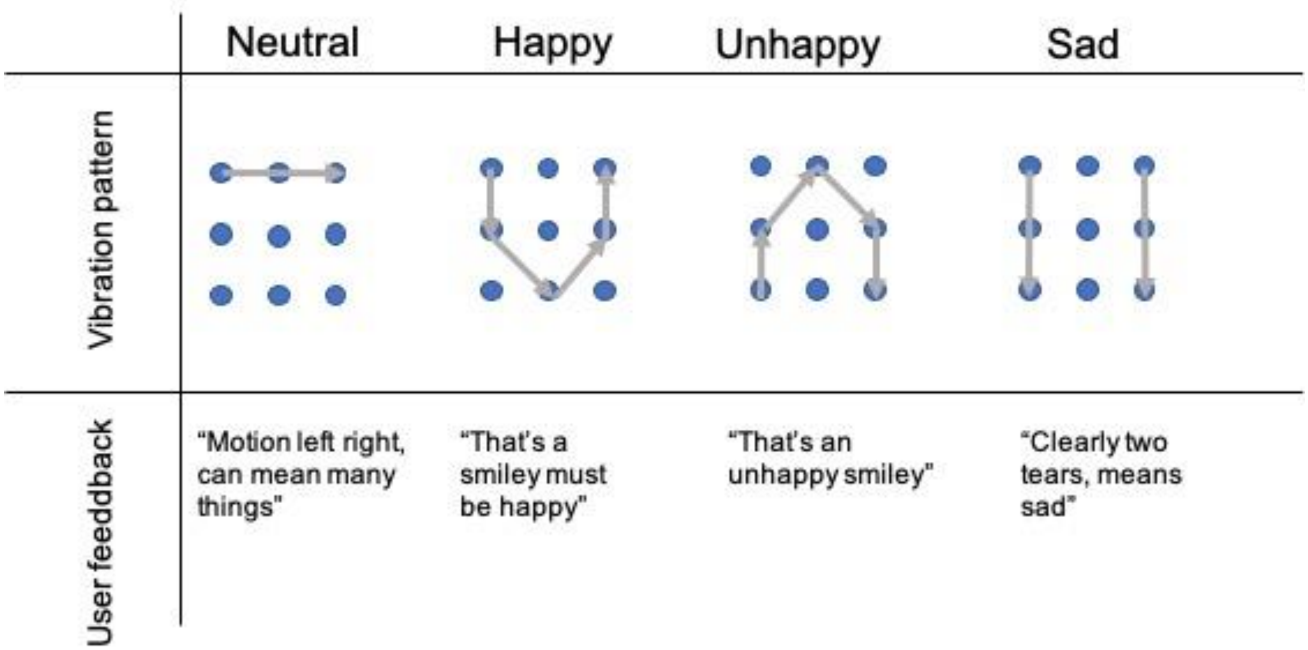


Figure 5 -A graphical representation of an example of how some of the SHC gestures were mimicked using vibration patterns. The grey arrows indicate which vibration motors switched on sequentially. In the lower row the paraphrased response of an SHC user to these vibration patterns is shown.

Finally, we investigated whether vibration patterns displayed on the back can be used to emulate Social Haptic Communication (SHC). Social Haptic Communication is a form of tactile sign language that is used to provide situational information via gestures made on the back of a person with deafblindness. Making a gesture with the hand provides information via pressure and vibrations feel quite differently from pressure. Therefore, we investigated whether SHC users with deafblindness were able to link vibration patterns to a sign used in SHC. We found that in several instances they indeed immediately linked a vibration pattern to the intended sign. Furthermore, users provided feedback to improve the recognizability of the vibration patterns and they indicated that they thought it would be quite easy to get used to the vibration patterns. This indicates that indeed vibration patterns can be used to emulate SHC.

The studies that we performed in SUITCEYES have advanced scientific knowledge of haptic perception and simultaneously had practical uses within the project in the form of design recommendations that were made based on the results. They have enabled us to implement clearly perceivable haptic feedback in the HIPI.

gamification

In this part of the project, we focused on creating designs that foster learning, enhance social experiences, and train a user's navigational skills and spatial orientation senses through use of gamification. Our development process was conducted in an iterative manner based on user requirements gained from user studies and co-design workshops.

Having drawn insights from existing literature on accessible gamified interventions and interviews, we defined a number of guidelines for creating games or gamified scenarios for individuals with deafblindness. As a result, we developed various concepts for games/gamified scenarios which facilitate and enhance learning, but also ones that enrich social interactions.

In the later stages of 2018, we completed developing our first version of a gamified vest, composed of six vibrating elements placed in a 360° configuration around the waist, each 60° apart from one another. This vest was utilised to conduct a field study with a total of 25 participants from Offenburg University that tested the Easter Egg Hunt gamified scenario. During this study, participants were asked to navigate through four different routes guided only by the vibrations of the vest. The routes themselves consisted of four obstacles and four checkpoints. Walking through a checkpoint would trigger a vibration on all elements, indicating that a participant was progressing well along the course. To simulate deafblindness, we covered the participants' ears and eyes. The participants reported to have thoroughly enjoyed this scenario and in general did not have problems following the vibrational guidance around the waist. However, a perception of progress feedback was deemed to be more difficult.

The second version of the gaming vest integrated the technical components into a flexible garment for the first time. The gaming vest of the second gamified scenario *Keep Your Distance* was expanded upon with a fisheye camera, capable of detecting QR-code-like markers even at larger viewing angles. Additionally, we replaced the new vibration motors providing a stronger sensation than the previous ones. The Keep Your Distance scenario was tested in a pilot study in mid-November of 2018 where participants walked through a predefined route twice. The game involves two players where one player assumes the role of a secret agent (player wearing the gaming vest) and the other acts as a suspect (represented through QR-code-like marker). The goal of the secret agent is to keep within an optimal distance to the suspect. While getting too close to the suspect will expose the secret agent's cover, staying too far from the suspect will enable him/her to escape. We presented a paper titled "Keep Your Distance: A Playful Haptic Navigation Wearable for Individuals with Deafblindness" at the 22nd International ACM SIGACCESS Conference on Computers and Accessibility (ASSETS 2020), receiving the People's Choice Award. Our video[16] also received the highest number of likes and engagement, with special recognition given during the conference's ceremony.

A third iteration of the vest was developed over 2020/2021, which incorporates a 4-by-4 grid of vibration motors on the back of the vest, enabling us to provide more complex messages and feedback to the user. We were also able to improve the overall robustness by taking advantage of 3D printed cases for the various hardware components. This was all brought together in a new garment created for this purpose.

In addition to the third iteration of the gaming vest, we also developed a new prototype which we have dubbed the Tactile Board[17]. This device facilitates communication for individuals with deafblindness, enabling them to initiate and engage in social interaction with other persons without the need for an intervener. Users can create words and simple sentences by drawing a multi-stroke pattern on a 4-by-4 grid of dots displayed on a tablet. This pattern is translated into speech and text displayed on-screen. Furthermore, the device can translate speech and typed text into vibrotactile signals to a user wearing a haptic wearable, such as the *Keep Your Distance* gaming vest. This allows a sighted and hearing person to communicate with a deafblind individual. Additionally, the software is fully customizable, where words and sentences can be added to the internal vocabulary list. To

[16] https://www.youtube.com/watch?v=bwPG-lzKVoc&ab_channel=SUITCEYES

[17] https://www.youtube.com/watch?v=36bj-6xvPmU&t=5s&ab_channel=SUITCEYES

make the user interface on the touch screen accessible for individuals with deafblindness, we developed a textile cover that covers the portion of the screen displaying the 4-by-4 grid with a tactile surface. Furthermore, the device can also be utilised to send queries to the SUITCEYES ontology. A related paper titled "*Exploring Low-Cost Materials to Make Pattern-Based Lock-Screens Accessible for Users with Visual Impairments or Deafblindness*'' was presented at ASSETS 2020.

Overall, we were very interested in exploring a variety of ways to use games and playful interactions to facilitate learning and to meet the expressed needs of individuals with deafblindness by using haptic technology.

one-to-many communication

In an educational setting, or when attending a meeting or a conference, the same social information can be relevant for multiple individuals. For instance, to convey what the mood is in the room, or whether there is applause or laughter. Traditionally, a number of different human interpreters have been needed to inform each receiver of such information individually. An achievement in the SUITCEYES project has been to develop a technique to convey a piece of information to multiple receivers simultaneously and if needed over long distances. How does this work? The person receives the messages through a set of vibration motors that are attached to a textile construction that can be put on the back of a variety of chairs. When a message is received, the vibration motors will switch on and off to form a haptogram or a pattern that emulates Social Haptic Communication, however, without the need for human touch in an automated haptic form.

In using this technique, only a single interpreter is needed to send a message comprising haptograms to multiple persons. This can be done, for example, by the use of the tactile board mentioned in the previous section. Furthermore, the interpreter does not necessarily have to be familiar with social haptic communication. We have developed a menu from which a sign can be chosen. Even voice commands can be used to select and send the corresponding haptograms to the receivers. Once a message is selected (from the menu or by voice command), the computer translates this to the corresponding haptograms to be displayed via the vibration motors.

When an internet connection is available messages can be sent over large distances. As an example, project members in Eindhoven, The Netherlands, succeeded in sending haptic messages to project partners in Offenburg, Germany.

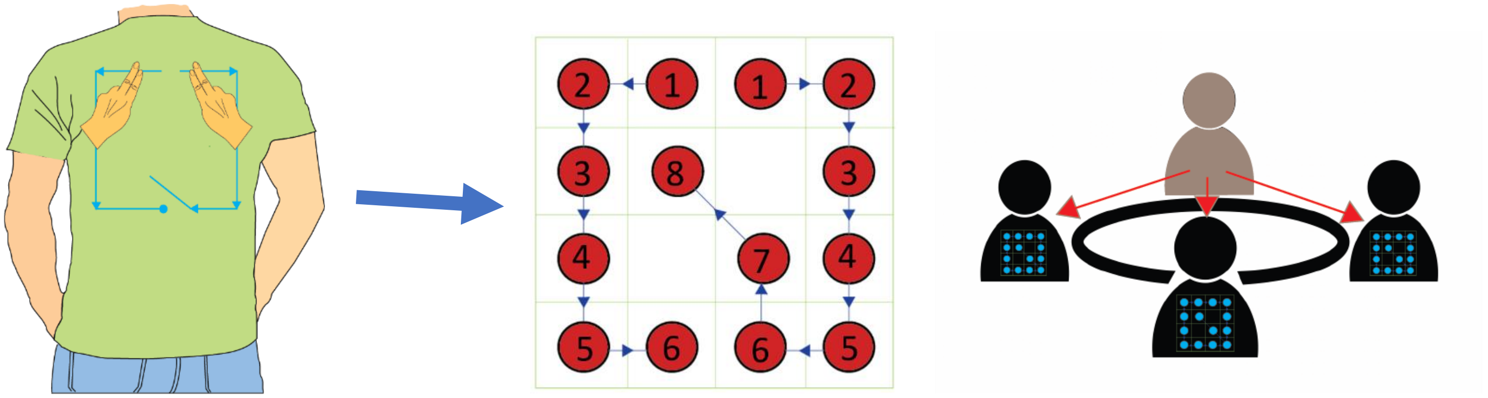


Figure 6 - Hand gestures for “room” in Social Haptic Communication is translated to its corresponding haptogram or vibrotactile patterns. Each dot represents a vibration motor that is switched on in the order indicated by the small arrow. This technique allows sending a haptogram to multiple users at the same time.

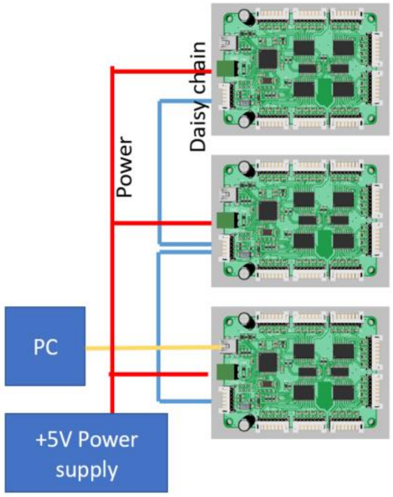
What this means is that the vibration motors of the project member in Offenburg played the haptograms sent from the Netherlands. By enabling one-to-many communication and conveyance of haptic messages over large distances this technique can be useful in many situations e.g., during Zoom meetings where each attendee is in a different location.

Since this technique enables sending haptic messages to an in theory unlimited number of people, it is suitable for very large audiences. Essentially, this opens up a way for haptic mass communication. Haptic information could be transmitted during a broadcast to a large audience. This could, for instance, be used to make press conferences or contextual information more accessible as it can be used to convey information about emotions, whether persons are entering the room and what the spatial layout is. By developing the language that is displayed by the vibration motors further, more possibilities can open up. It might be possible to provide haptic information about sports matches by haptically representing the position of a soccer ball on the field.

the haptogram design toolkit

In order to convey messages to the user, we utilize vibrotactile actuators placed within wearable garments or other surfaces such as the back of a chair. For this to work there is a need for both hardware and software. In addition to other controller boards, designed for other purposes within SUITCEYES, we have also designed two separate printed circuit boards (PCBs) - with 32 and 40 channels respectively as part of our haptogram design toolkit. Each channel of these boards can be connected to an actuator. These boards can be used separately or daisy-chained together to enable the use of a larger set of actuators. For example, by connecting three 32 channel boards we will be able to connect with 96 actuators which can be placed on different appropriate parts of the body for conveyance of tactile messages by haptograms.

As mentioned earlier a haptogram is a tactile symbol or synthetically generated haptic pattern, with a meaning, to be communicated as stimuli to the human body. The haptic patterns in the haptograms are inspired by the hand gestures made in Social Haptic Communication. A haptogram can be mapped to one or more parts of the body. This is done, for example, by activation of vibrotactile actuator motors placed within a garment. The pattern in each haptogram is formed by activating different actuator motors, or nodes, one after another in a predefined order. To instruct each of the actuator motors to vibrate for a given time and with a given intensity requires a piece of code. Therefore, for each haptogram which is built up of a sequence of nodes being activated in a predefined order, one would need an instruction for activation of



each node (also called a frame). For example, the instructions required for the haptogram “danger” which looks like a cross (X), as mentioned earlier, can look something like this:

```
<haptogram name="danger" template="Grid 5x5">
    <frames>
      <frame duration="1000">255,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,100,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,0,0,0,0,0,0,100,0,0,0,0,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100</frame>
      <frame duration="500">0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,200,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,0,0,100,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,0,0,0,0,0,0,100,0,0,0,0,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100,0,0,0,0,0,0,0,0</frame>
      <frame duration="1000">0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,0,100,0,0,0,0</frame>
    </frames>
```

Each line or frame relates to one of the nodes in the haptogram. For example, the first line indicates that the first node (top, left) is activated for a period of 1 second (or 1000 milliseconds) with the max intensity of 255. While simple enough, writing of the instructions manually can be tedious, time consuming and prone to error. We have therefore created an application software that facilitates design of haptograms and encoding of these instructions. This software allows for the design of haptograms on different grid sizes (3x3, 4x4, 5x5, 6x6 and 12x8). This tool currently offers options for adding and deleting haptograms and adding or deleting frames within each haptogram, activation of multiple nodes in sequence or simultaneously, specification of duration of each frame, intensity of vibration for each node, showing channel index to specify the exact correspondence between each node and the respective actuator, and more.

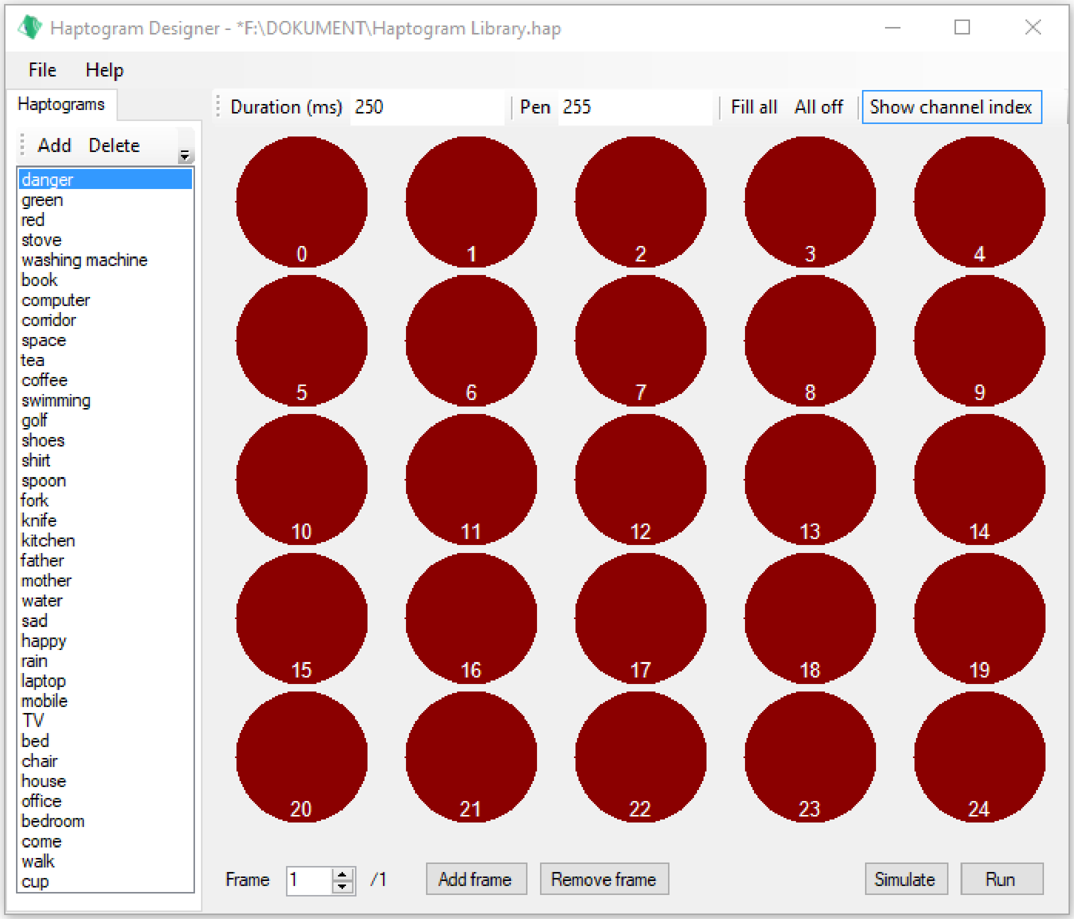


Figure 7 – Screen shot of the haptogram design application tool.

the SUITCEYES platforms

Like all projects, SUITCEYES would have a limited lifetime. Therefore, from the start, we intended to facilitate the continuation of the work initiated in the project, beyond its conclusion. Furthermore, due to the diversity of the needs and aspirations of the target users, we intended to create technologies that would be customisable. Based on these thoughts, a couple of decisions were made right from the start. First, technologies developed within the project would have a modular format to enable mix-and-match, as needed, based on specific requirements. Second, to create proofs of concept and prototypes that could be built upon and expanded (whether by us or by others) beyond the project.

Accordingly, the research and other activities conducted in the project have resulted in a number of platforms that can be used and built upon even beyond the project's end. These include:

(a) the HIPI as the project's main technological platform,
(b) the SUITCEYES GitHub account which acts as a platform for the sharing and further development of the codes and software created in the project,
(c) the SUITCEYES network as a platform for continued conversations and collaborative activities beyond the project end,
(d) the SUITCEYES website as a communication platform and a reservoir for publications and other resources, which we intend to upkeep for a foreseeable future.

a) the SUITCEYES HIPI

The core technological innovation in SUITCEYES has been the development of a *Haptic Intelligent Personalised Interface*, or the HIPI. The HIPI has been intended to act as a platform to enable further developments and inclusion of additional components by us or by others as needs arise and resources become available.

During the project, we have experimented with and designed various technological components for the HIPI that can be used individually or coupled with one another to achieve varying objectives. These include sensor technologies, computer vision and visual analysis for capturing environmental cues or for active object search, queries from the user to the system and conveyance of messages from the system to the user, use of smart-textile based interfaces, hardware and software for design and use of haptic communication, different games and related technologies. This means that while we refer to this platform as "the HIPI", or in singular terms, there are currently multiple constellations of different components brought together in different versions. For example, for the purposes of our research and experiments, the combination of components brought together for the games differ from those brought together for the purpose of active object search. However, all the components are compatible and if needed, they can all be brought together as a complex whole. Furthermore, the current components can be extended or new components added by interested parties. For example, new games can be added, the SUITCEYES ontology can be extended, further navigation and object search functionalities developed, and so on. In other words, the HIPI (and all its variations) forms the main technological platform of the project.

The current variations in the HIPI include a number of vests from fully adjustable, (designed for the purposes of experimentations and which fit different sizes and body shapes of the study participants), to a customised tailor-made vest (designed to fit a specific user with various sensing devices and electronic units fitted for optimal use by the intended user). These vests are used for experiments with perception studies, computer vision, active object search and gamified scenarios. The HIPI has also been made as a dress to demonstrate the potential for creation of aesthetically-pleasing fashionable clothing which at the same time can house sophisticated technological components. In addition to these, there is a further wearable, or a multi-panel suit, that is intended for conveyance of semantic content to different body parts. Not all HIPI types are designed as wearables, for example a HIPI called *chairable* is designed to be mounted at the back of a typical office chair to convey messages to the person sitting in the chair. This version of the HIPI is ideal for experiments with multiple study participants who can easily sit in, and get out of a chair one after another or for the purposes of one-to-many communication in an educational setting or at meetings and conferences.

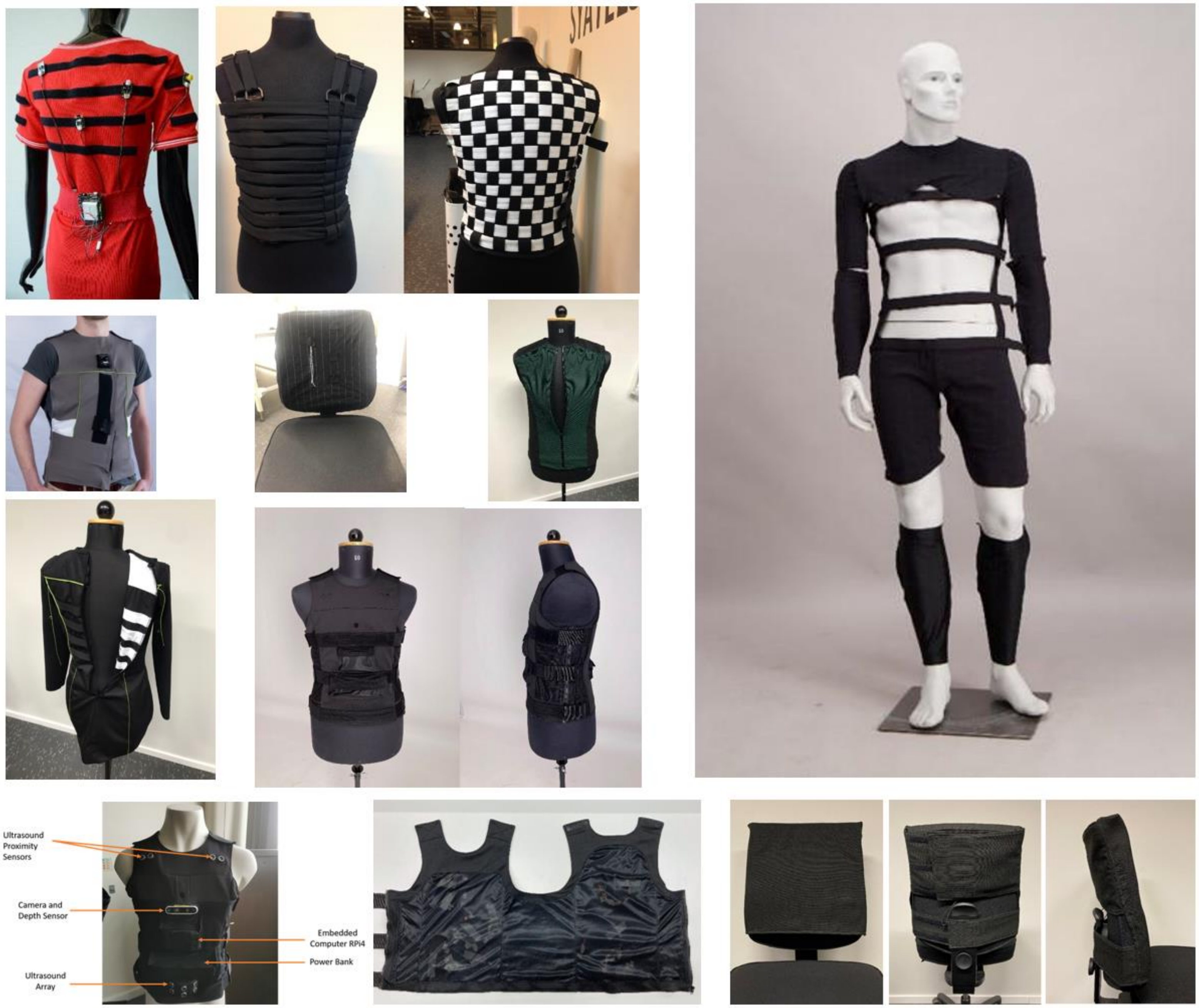


Figure 8 – Various versions of the SUITCEYES HIPI, used for different purposes.

b) the SUITCEYES GitHub

The SUITCEYES GitHub page, SUITCEYES-Project[18], contains the software code that was developed for the SUITCEYES project and acts as a platform for sharing this material with a broad audience and which facilitates further development of these software solutions by us or others in the future. Modules such as the Tactile board, the Vibration pattern player and the Visual Analysis platform are available with easy-to-follow instructions on how they can be set up and executed. This way, the developed software can be potentially utilized as is, modified, or be used as a platform for additional modules. These modules can be developed on top of the existing software, utilizing the created SUITCEYES software for different projects. The software has been licenced with the MIT and Apache-2.0 licences.

c) the SUITCEYES network

During the past four years, we have established a broad network of contacts and close collaborations with a large number of people and organizations. These include top researchers studying various aspects of deafblindness and related technologies, key resource people in national and international organisations working with issues of deafblindness (e.g., DBI[19], WFDB[20], Sense[21], nkcdb[22], Nordic welfare[23], SPSM[24], Bartiméus[25], CFD[26], CRESAM[27], BIBB[28], Taubblinden-Info[29], Hellenic Association of Deafblind[30], Royal Dutch Kentalis[31], fsdb, Mo Gård[32], Eikholt[33], and more), policy makers, and individuals with deafblindness. We believe that this strong network of contacts provides a strong platform for continued discussions and future collaborations. Interest for such activities has already been expressed and a number of project members are committed to organized quarterly meetings with those interested beyond the project end. The purpose for these meetings is to initially plan and get involved in different actions including: information sharing about recent developments or upcoming events, collaborations on joint proposals or co-authored papers, joint student projects, student exchange, and more.

[18] https://github.com/Suitceyes-Project
[19] https://www.deafblindinternational.org/
[20] https://www.wfdb.eu/
[21] https://www.sense.org.uk/
[22] https://nkcdb.se/
[23] https://nordicwelfare.org/en/about-us/
[24] https://www.spsm.se/
[25] https://www.bartimeus.nl/
[26] https://www.cfd.dk/
[27] https://www.cresam.org/
[28] https://www.bibb.de/
[29] http://www.tbl-info.org/
[30] https://www.omke.gr/
[31] https://www.kentalis.com/
[32] https://www.mogard.se/
[33] https://www.eikholt.no/

d) the SUITCEYES website

The SUITCEYES website, https://suitceyes.eu/, designed with accessibility considerations in mind, is a further platform for communication, sharing information, and making the research results accessible to a broader public. Typically, project websites hold a wealth of information but unfortunately cease to exist soon after the project-end. We intend to manage and upkeep the project website for the foreseeable future and further populate it with more information even after the end of the project. It can then also include contents related to the joint activities that we intend to engage with after the project.

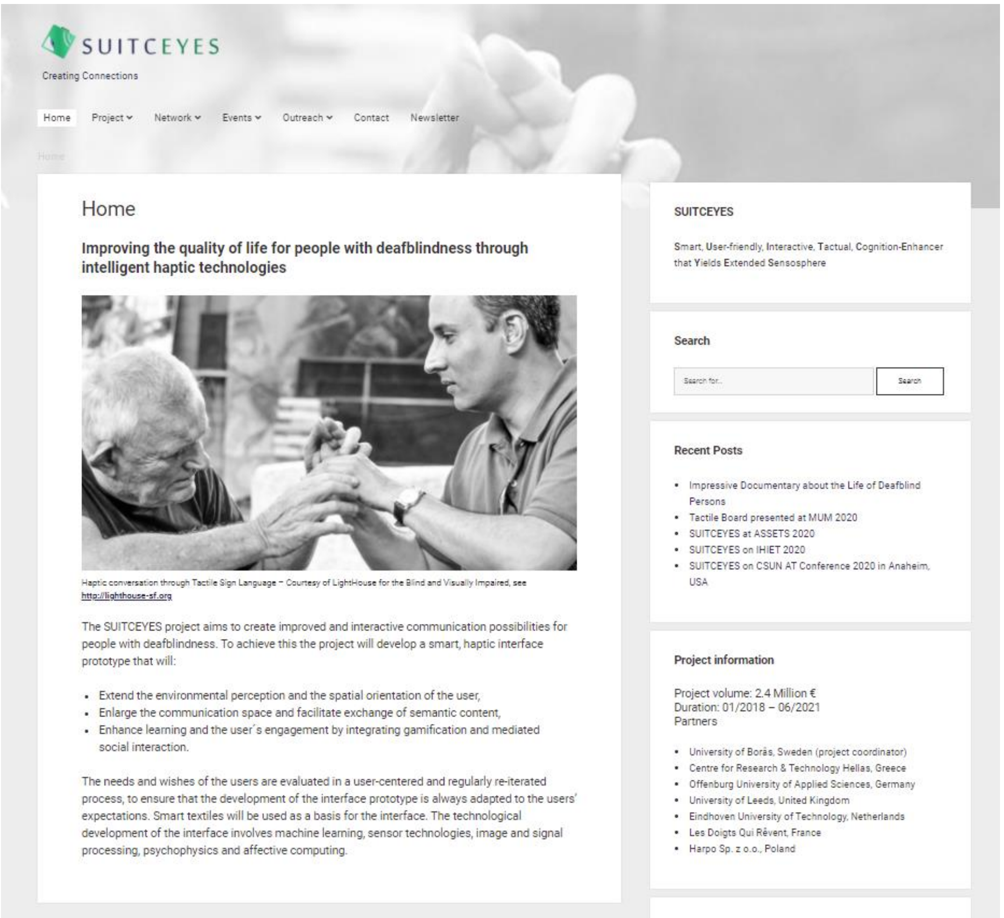


Figure 9 – Screen shot of the SUITCEYES website.

knowledge sharing and exploitation

Dissemination, knowledge sharing, and exploitation activities of the SUITCEYES project were overviewed and managed by as a specific subsection of the project. This involved the dissemination of project information and results to different stakeholders using different strategies according to the communication needs of each audience, such as people with deafblindness, and academic and industry communities. Knowledge sharing and exploitation activities aimed to ensure socio-economic impact of the project results, including a proposal for the exploitation of our achievements beyond the project's end date.

While developing these activities, we have built relations with stakeholders and a larger community around the project's interests, especially with people with deafblindness, researchers and the industry sector. Interaction with these stakeholders was critical not only to enhance project awareness but to gather feedback on our results and ideas. We have also analysed the environment in which the SUITCEYES results will be used in terms of applicability to the targeted user community and market opportunities. Building a project community was also important to promote stakeholder engagement aiming for a sustainable development of SUITCEYES beyond the project's lifetime. We have defined exploitation strategies and managed innovations within the project.

During the last year and a half, we had to share knowledge, disseminate project results and build a community with target users remotely, without direct contact due to the ongoing COVID-19 pandemic. Similarly, we had to interact with project partners and cope with difficulties that this caused. Indeed, the whole society had to find and learn new ways of communicating. Therefore, the pandemic may have been instrumental in creating a better understanding of the human needs for communication and how barriers to communication (which most of us have only recently experienced due to the pandemic) have been affecting people with deafblindness on daily basis. Hopefully we will witness long lasting effects for improved inclusion.

We need design solutions that are truly inclusive and accessible; SUITCEYES has been a step in the right direction. Many research, adaptation and market challenges remain to be addressed in follow up efforts and in future projects.

covid-19 and the project

Like all aspects of life, the COVID-19 pandemic also affected the conduct of our project on different fronts. SUITCEYES by nature is a user-centred innovation project and therefore, access to both users and technological components are at the core of the project.

We had planned extensive user studies, and involvement of potential users for ideation and feedback, from the beginning. After the half term review of the project (summer of 2019), recommendations were made to even go beyond our initial plans and involve potential users more heavily in different aspects of the design and co-creation activities. Consequently, in autumn of 2019, we made many new connections, extended earlier plans and booked many activities involving people with deafblindness. A collaborative project such as SUITCEYES requires joint efforts from multiple partners, and collaboration with participants with deafblindness requires further planning, and involves a set of challenges regarding time coordination (between project members and participants, assistants and interpreters), and decisions about suitable venues, lodging, travel arrangements and so on. Considering the number of people (and countries) involved, and all the arrangements that needed to be made, we planned and booked different activities to take place from the spring of 2020. As an example, we had made arrangements for the whole consortium, a group of the project advisers, and a team of news reporters from EuroNews to spend three full days with a large group of people with deafblindness, interpreters, assistants, experts in issues of deafblindness and more at Eikholt, which is a National Resource Centre for the deafblind-related issues and a living arena for synergies and competence development in Norway. The participants and their support people and some project members would live on location and the others very close by. In this way we would get access to a living lab. We had different ideation and co-creation workshops (plenary and in smaller groups) planned. But as time grew closer to the event, the prospects of us being able to travel to Eikholt became more and more unlikely, and shortly before the event the plans had to be cancelled. We revisited a similar set-up multiple times with the hopes of improvements in the situation without success due to continued dangers and this and other similar plans had to be cancelled, as restrictions remained throughout the rest of the project. This meant that we only managed much smaller activities with just a few participants in person, a few other activities were achieved online, and some activities could not be conducted.

Travel restrictions, closed labs and inability to gather in the same location, also hampered our own collaborative work. Again, most parts of the project required collaborative efforts. While we would typically meet in person in consortium meetings or smaller groups for developmental work, this was no longer possible. Therefore, all the devices and prototypes required duplication and postage and this meant delayed testing and corrections. At times posted items would go missing only to arrive months later. The situation was aggravated further due to the lack of access to the electronic components; not only did we need to duplicate different units; we sometimes could not even locate and purchase the components required just for one.

Another effect of the Covid pandemic was the cancellation of conferences or hackathon type events. We naturally took steps and reorganised our work and found workarounds but, in the end, due to the delays in access to required components, closed labs, inability to collaborate in person in areas that required more than one participant, like many other projects we were forced to seek an extension which was granted. Accordingly, the end of the project was moved from the end of December 2020 to the end of June 2021. This extension without additional resources also created some challenges. For example, some members of the project were on fixed term contracts, and due to leave at the planned end of the project. To extend their work for an additional six months without additional resources meant that either their participation would need to end or additional resources would need to be injected to the project by the partner organisations or other arrangements made. We are therefore happy to see a strong conclusion to the project despite the difficulties faced.

main achievements

The SUITCEYES project had set out to achieve a number of objectives in three different areas. Research and Technology Development (RTD) objectives were:

- To develop a haptic interface for informing of the physical surrounding environment.
- To capture, translate and semantically represent environmental clues

As presented above, these objectives have been achieved through the technological developments made in the project. The HIPI is a smart-textile-based haptic interface that utilizes haptograms for keeping the user informed of the surroundings that are detected by the system. It allows the user to pose a set of queries to the system, for example the user can ask “where am I” or “where is my laptop” and so on. The sensor technologies and computer vision elements of the HIPI capture environmental information such as recognising that the user is in a bathroom or an office or a corridor, or that there are three people in the room of which two are known to the user, or that the water bottle that the user is looking for is on top of a chest of drawers about three meters to the left of the user, or the user's mobile phone was last detected by the HIPI around 20 minutes ago in the kitchen.

SUITCEYES also intended to achieve a set of user-oriented objectives including:

- To extend users' independent perception of the physical surrounding environment.
- To extend users' communication capabilities by facilitating communication or extending the range of haptic vocabulary at their disposal.
- To facilitate learning and extend fun life experiences through gamification and affective computing

These objectives have also been achieved. The HIPI can inform the user independently in the absence of personal assistants or interpreters about some elements of the surroundings. By use of haptograms a new mode of communication has opened up to the users. To reduce the demands of learning a new language and to increase recognizability, the haptograms are designed to resemble the SHC hand gestures already known to many. Finally, the gamified scenarios developed in the project facilitate learning in a fun and motivational manner.

A further user-oriented objective was defined as follows:

- To improve the circumstances in which the users find themselves.

In addition to this final user-oriented objective, we had also defined two societal objectives as follows:

- To identify and raise awareness of the priorities and aspirations of participants living with deafblindness for leading active and fulfilling lives, and the barriers to achieving these.
- To identify good practice in policy frameworks across the participating countries and make recommendations for where policy could be improved.

Again, these objectives too have been achieved. The extensive user study involving 81 interviews with 79 participants in five European countries, in addition to many other participatory workshops, meetings, and events helped us identify and better understand the priorities of participants who live with deafblindness. We have raised awareness about these priorities and aspirations as well as challenges and barriers in leading active lives through publications and also by other means. For example, by the information shared on the project website, through meetings, seminars and targeted presentations (e.g., presentation of the project to the members of the Royal Swedish Academy of Sciences, or presentation of the project to the Swedish Minister of Culture and Democracy), by attending conferences and other events, by organizing various events including three larger symposia, and by engaging with the popular press (newspapers, radio and TV programs) in order to inform a broader general public. Furthermore, an extensive policy study was conducted within the project in five European countries examining policy frameworks in the studied countries resulting in a set of recommendations. Furthermore, various opportunities were created to engage with policy makers and other policy scholars in order to promote further improvements of legal frameworks that govern the societal circumstances in which people with deafblindness find themselves.

It is rather difficult to gauge the true level of impact that these activities may have in the long run, in raising awareness and improving societal circumstances. At the very least, there are now around 30 researchers or members of the project who have gained an in-depth understanding of related issues far beyond their knowledge of deafblindness when the project started. Furthermore, all the seven partner organisations involved in the project have exceptionally become involved in issues of deafblindness and also inclusion, participation, accessibility and equal opportunities for all. But we already know that the reach of our effort goes far beyond that. We can see statistical evidence about the number of times our publications are read or cited. A number of posters, demos and full papers produced within the project have been deemed by peers as noteworthy and have received awards. There have been multiple news articles, radio and TV programs about the project broadcasted (with or without our involvement) with follow up contacts by the general public who have shown interest in the topic. Those of us involved in teaching and student supervision have also fed knowledge gained through the project to our educational programs and student projects, creating the potential and incentive for continuation of our research by others. Therefore, we hope and believe that we have easily achieved all the different objectives that we had set for the project from the outset.

highlights

We will next explain about a few of the more notable activities in the project that have been instrumental in networking, and sharing research results with the broader audiences.

Figure 10 – Project logo in tactile format and symposium program in Braille.

SUITCEYES symposia

During the project's lifetime, we have organized three different symposia with international participation.

From Touch to Cognition - January 17, 2018 – The first symposium in the project was a half-day event, held in conjunction with our first face-to-face consortium meeting, right at the start of the project, as a strong kick-off to the project. The planning process had started soon after receiving notification about the success of the project proposal. The ambitions for this event were to launch the project, informing the community about our research, and also to include talks about topics that the consortium as whole would need for a shared common understanding. The program therefore included talks by experts in deafblindness, each representing various related national agencies in Sweden (including a speaker with deafblindness). In addition to this there were also talks on haptics and haptic interfaces as well as a talk on gamification titled "games

Images on this and following pages depict scenes from various SUITCEYES events and activities.

for change". Around 50 people participated in the event with much interest both by the participants and also by the press. Those initial news coverages subsequently lead to many contacts by interested parties, mainly from the Nordic countries. Various seminars or bilateral meetings followed and our network of contacts as well as the membership in our advisory boards grew. Those project members who had not had much previous contact with issues of deafblindness were enriched by the knowledge and the first-hand experiences gained at the symposium.

Haptic Communication – Breaking the Barriers - August 22, 2019 - Typically as the consortium members have gathered together for various face-face-face meetings we have tried to optimise those opportunities and this was also the case when we all met for the mid-term review of the project. Again, much planning was done and external funding was sought for the organisation of our second symposium which this time was a full day event.

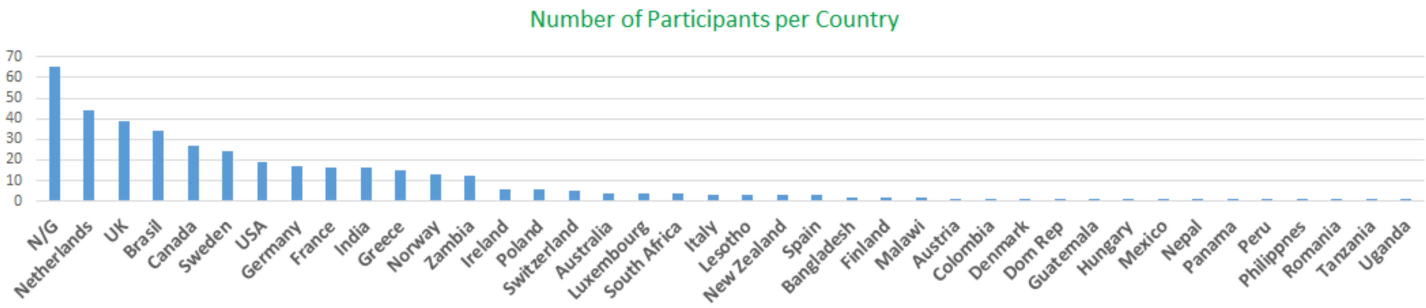
The symposium was attended by over 80 people. An intention behind this symposium was to create

a learning experience both for us and for the audience. By this stage of the project, we had achieved some results and the opportunity was used to share some of these findings with the audience. We also took the opportunity to learn from others, for example we had a very informative and interesting talk by the Vice President of World Federation of Deafblind (WFDB) that informed the audience about the work done by WFDB and deafblindness based on personal experiences. A talk by the Director of the IJN Sign Language Group about 'visual

to tactile sign language' and two other talks by experts related to 'social haptic communication' and its use were very timely for us in the project as we were just embarking on the semantic and linguistic parts of the project. A further talk about 'EU funding and research for e-inclusion' was also of much value to

researchers who were interested in future opportunities. In addition to these talks that were informative for the audience and for us in the project, we also took the opportunity to engage and connect with top decision makers who could influence policy and decisions related to issues of deafblindness. For example, an invited speaker was the Director-General for the Swedish Agency for Participation. By this we were able to share some of our findings about the challenges experienced in daily lives and valuable informative conversations were had. We were also able to connect with experts in co-creative cultural experience with, by, and for people with disabilities. This symposium concluded with an impressive Japanese Taiko drums performance that was a demonstration of how even music that cannot be heard can be enjoyable by stimulating other senses besides sight and hearing.

Living through Touch – Smart Haptic Communication for Inclusion, Accessibility and Participation - May 17-19, 2021 – With the end of the project in sight, we intended to hold a final public event that had multiple objectives, including (a) sharing the project's final results with the community that had supported the project throughout, and broader audiences; (b) bringing together all the different connections that have been made during the project (c) engaging organizations and technologists who may potentially be interested in utilizing and building upon our work, (d) engaging with top decision makers, informing them about our findings and exploring how they can help improve the social circumstances that people with deafblindness face on daily basis, and finally (e) to promote and initiate a broad conversation on how the efforts started within SUITCEYES can be continued and /or other initiatives started so that the end of the project does not mean the end of the important work that was initiated by the project. This time the symposium became a three-day event and due to the pandemic, it was held online and was timed to enable potential participation from other parts of the world. There were also measures to make this event as accessible as possible by providing live transcription and sign language interpretations. More than 400 participants from 39 countries had registered. Of course, considering the time differences, not everyone could attend the full symposium and typically there were around 80 to 130 signed in at each session, where in a number of cases several people were attending at the same location using the same user login. At the end of each day, an online mingle was held where freer conversations could be had with the participants. It was very encouraging to hear the positive feedback and to see so many participants joining the symposium at locally uncomfortable times.



When it comes to the public events arranged by the project, this final symposium played an important role and achieved all its intended objectives. (a) The project results were presented and other researchers in the field were also invited to present their work. This created a bridge for potential future collaborations in research among the SUITCEYES project members and others interested in similar topics. (b) We also created a space for international organizations such as DBI, EDBU and Sense to address the audience with invitations for involvement and important messages such as “Within the challenge, lays the opportunity”, “Nothing about Deafblind without Deafblind”, and “No one left out of life”. (c) Three consecutive sessions were then dedicated to bridging the gap from research results to usable products. As it is common in most research and development projects, we have created useful technologies in the form of proofs of concept and prototypes with much potential. However, it would be ideal if our efforts could be turned into ready products usable by the intended target group. As the bounds of the project do not allow these last steps, an intention with these sessions was to involve some organisations that may be able to continue our work or alternatively describe the process for the audience and help them see how they can be instrumental in making this happen. (d) Three further sessions were dedicated to policy issues, first presenting the extensive policy study conducted in the project and then engaging in conversations about the steps to be taken to improve legal frameworks governing the societal conditions for inclusion, participation, accessibility and equal opportunities for all. (e) The following sessions in the symposium had a common theme of “Beyond SUITCEYES”, where a few speakers with deafblindness drew on their personal experiences and outlined some paths forward, then some of the project’s advisers gave their take on SUITCEYES and finally in a conversation between the project members and the audience some steps forward were discussed.

The program included renowned researchers in the area as well as top politicians (e.g., the Swedish Minister for Higher Education and Research, a Swedish MP, a member of Policy & Delivery Division, Directorate for Mental Health & Social Care, Scottish Government, Health and Social Care Alliance Scotland “the ALLIANCE” and Coordinator for the Nordic Cognition Network in relation to Deafblindness as well as the Head of Unit “Accessibility, Multilingualism & Safer Internet”, DG CNECT, European Commission); heads of international organizations dealing with deafblindness as well as researchers and activists with deafblindness[34].

This event was a step in achieving some of the project objectives mentioned earlier, especially regarding raising awareness and improving the circumstances in which people with deafblindness find themselves.

consortium and advisory board meetings

As mentioned, the above public events were typically organised in conjunction with different project consortium meetings. We also used those gatherings for other purposes such as holding joint sessions with our project advisory board members. In this way we optimised the required planning and the travel efforts while minimising the costs.

The first project consortium meeting was held in Borås, (SE), on January 17-19, 2028, starting in the morning of the first day with the project's first symposium, which was then followed up with continued conversations with and input from our advisory board members on the same day. The first day concluded with sponsored activities that provided an inviting space for social interactions and for the project members and some advisers to get to know one another even better. The following two days of the consortium meeting were used to plan ahead and initiate our research and collaborative work for the duration of the project.

The second consortium meeting was held at the University of Leeds (UK), on July 10-11, 2018 and this time, the program included talks by and conversation with members of Leeds Disabled People's organisation about the Social Model of Disability, a talk by and discussions with a professor of law who is the Joint Director of the University-wide interdisciplinary Centre for Disability Studies and Co-ordinator of the Disability Law Hub, at the University of Leeds, followed by an extended workshop with members of Deafblind UK, again enriching the consortium with further knowledge and insights, as well as providing valuable feedback. The rest of the time was used by the

[34] The full program can be found on the project's website (https://suitceyes.eu/program/).

members to inform one another about the progress in the project so far and plans ahead. Further focused work by some of the members also took place after the end of the consortium meeting in order to reduce travelling costs and extend the utility of many being in the same location at the same time.

The Third Consortium meeting was held in Thessaloniki (GR), on 15-17 April, 2029. Again, the opportunity was used to inform one another about all the activities and research in the project and to hold various plenary or group meetings and workshops, with focus on integration issues, upcoming symposium, haptic interactions, joint publications, legal and policy aspects for national and synthesis reports, and planning ahead for the upcoming project mid-term review. Conversations were also had on definition of project platforms and prototypes and Analytical Data and User Data working groups. A further event in form of a SUITCEYES Hackathon also took place in Thessaloniki on July 2-3, 2019, and although this was not a consortium meeting attended by all members, many partners working on technical aspects of the project attended this event and collectively furthered the research and innovation conducted in the project.

The fourth consortium meeting took place again in Borås, on August 21-23, 2019 in conjunction with the project's second symposium and its mid-term review. As many travellers who intended to attend the symposium on the 22nd would arrive the evening before, we took the opportunity to organize a very informative and useful meeting with project advisory boards on the 21st. Many were present in person, others joined us online. Again, latest research results were shared with them and valuable feedback was received. Some advisers with deafblindness were also able to test and experience some versions of the HIPI in person and again provide feedback.

The fifth and final in-person consortium meeting was held in Offenburg (DE) on December 5-6, 2019. External funding was acquired to enable travel and participation of a few of project advisers in this event. As usual, the occasion was used for various presentations, informing the whole consortium in more details about latest developments and then to conduct collaborative work and have discussions that require broader input. There were also working sessions, testing, and participatory workshops involving one of our advisers with deafblindness.

We also fine-tuned plans and arrangements for upcoming events, many of which involved participatory co-creative workshops with people with deafblindness and collective on-location collaborations among different members. Little did we know at the time that all those plans would have to be cancelled or changed due to the Covid pandemic.

There were further consortium meetings held in 2020 and 2021, but these all took place online via Zoom. Again, as usual, current works were presented, plans were discussed, and project advisory board meetings were held with the project advisers, but we were unable to conduct collective workshops, lab work, or involve participants with deafblindness. Nor could the advisers feel and test the most recent developments and offer feedback based on those tests and actual experiences. While in terms of travel arrangements these types of consortium meetings were less expensive to arrange, the lack of access to users and inability for the partners to be in the same location at the same time (even from the same team at the same partner organisation) came at a great cost to the project and the development and testing that could be conducted under such circumstance.

publications

There have been a number of peer-reviewed scholarly publications within the project, a list of which can be found on the project website (https://suitceyes.eu/publications/). In addition to what is listed there, there are a number of other publications that have been submitted or are in various stages of being developed. Therefore, those interested are invited to view this page again later on even after the project-end for a more comprehensive list. Meanwhile, we would like to highlight that a number of items produced in the project have received acknowledgements as follows:

- **Best Work in Progress Award - Finalist** - Plaisier, M.A., Holt, R. J., and Kappers, A.M.L. (2019). Numerosity perception of temporally grouped vibration pulses. IEEE World Haptics Conference, Tokyo, July 9-12, 2019.

- **People's Choice Award** - Gay, J., Umfahrer, M., Theil, A., Buchweitz, L., Lindell, E., Guo, L., Persson, N-K and Korn, o. (2020). Keep Your Distance: A Playful Haptic Navigation Wearable for Individuals with Deafblindness. In *The 22nd International ACM SIGACCESS Conference on Computers and Accessibility* (*ASSETS '20*). Association for Computing Machinery, New York, NY, USA, Article 93, 1–4. https://doi.org/10.1145/3373625.3418048

- **Most liked video presentation** - Gay, J., Umfahrer, M., Theil, A., Buchweitz, L., Lindell, E., Guo, L., Persson, N-K and Korn, o. (2020). Keep Your Distance: A Playful Haptic Navigation Wearable for Individuals with Deafblindness. In *The 22nd International ACM SIGACCESS Conference on Computers* and Accessibility (ASSETS '20). https://www.youtube.com/watch?v=bwPG-lzKVoc&ab_channel=SUITCEYES

- **Best Poster Award** - Nandkumar, K., Schulz, A. S. & Korn, O. (2020). Wearable or HMD? how to support tactile navigation. In Proceedings of the 13th ACM International Conference on PErvasive Technologies Related to Assistive Environments (PETRA '20). Association for Computing Machinery, New York, NY, USA, Article 78, 1–2. https://doi.org/10.1145/3389189.3397644

- **Best Paper Award** - Darányi, S., Olson, N., Riga, M., Kontopoulos, E., & Kompatsiaris, I. (2019). Static and Dynamic Haptograms to Communicate Semantic Content—Towards Enabling Face-to-Face Communication for People with Deafblindness. SEMAPRO 2019, 16–20.

- **Best Paper Award** - Olson, N. & Maceviciute, E. (2020). Information worlds of people with deafblindness. In *Proceedings of ISIC, the Information Behaviour Conference, Pretoria, South Africa,* 28-30 September, 2020. Information Research, 25(4), paper ISIC2020. https://doi.org/10.47989/irisic2012

innovation radar

Of other acknowledgements, SUITCEYES also received recognition in the form of being picked by the **European Commission's Innovation Radar** (highlighting excellent innovations) and was showcased from 20th of July 2020 on European Commission's Innovation Radar platform (https://www.innoradar.eu/resultbykeyword/suitceyes).

concluding remarks

The SUITCEYES project started at the beginning of 2018 with the aim to develop haptic communication technologies for people with deafblindness towards improved independence and participation and in order to enhance their communication, perception of the environment, knowledge acquisition, and conduct of daily routines. More than three years on, we believe that SUITCEYES has achieved what it had set out to do despite the unforeseeable challenges that were faced due to the pandemic, although had we been able to follow plans, as initially perceived, it is likely that we would have come even further. Due to closed labs, travel bans, lack of access to potential users, inaccessible electronic components and inability for the project members to meet in person and conduct developmental work and testing together for a very long period in the project, major delays were caused and some development ideas had to be replaced with alternatives that were possible given the situation.

Regardless, the SUITCEYES team has remained strong with much enthusiasm to continue the work initiated in SUITCEYES in follow up activities. Many members have already looked into other collaborative opportunities. Furthermore, based on popular demands conveyed by the project's network, a group of members have already plans for regular quarterly meetings beyond the project-end, with other interested parties for continued collaborations.

We use this opportunity to thank all the many people who have supported the project throughout including the project collaborators, participants and speakers at the different SUITCEYES events, the Project's Advisory Board members, the different EU-appointed Project Officers, and the Project Reviewers who have all provided the project with valuable feedback. We especially like to thank all the anonymous study participants who have generously shared their experiences and insights with us, without whom this project would not have been possible.

Those who participated in the SUITCEYES project welcome new connections and future collaborations. The project website will remain active for a few more years, and offers the option to contact us.

Thank you all, and we look forward to future opportunities and further collaborations.

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